Belle time-dependent gamma measurements

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Outline

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- Conclusion

Introduction

In the Standard Model, irreducible complex phase in Cabbibo-Kobayashi-Maskawa (CKM) matrix cause the *CP* violation.

$$V_{n=3} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \simeq \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

Wolfenstein Parameterization

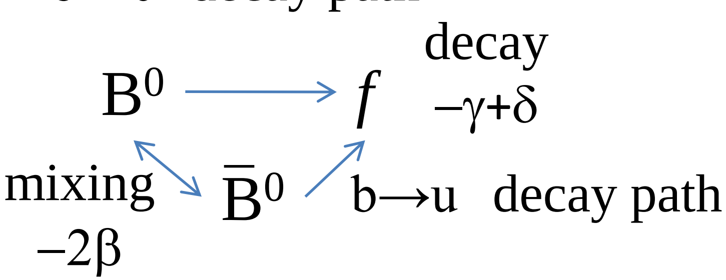
One of the unitarity condition of CKM:

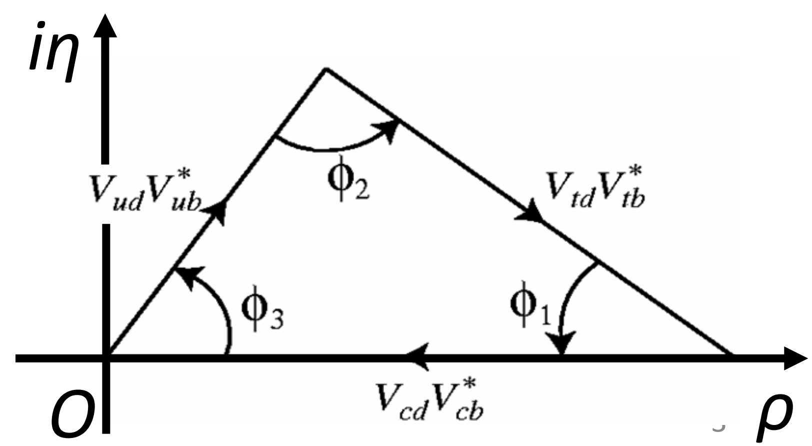
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

$(\phi_1, \phi_2, \phi_3) = (\beta, \alpha, \gamma)$

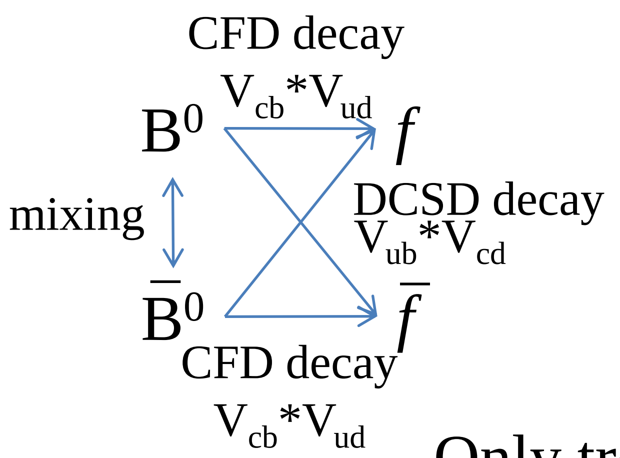
Time-dependent γ measurement

b→c decay path





$D^{(*)}\pi$ Time-dependent CP analysis



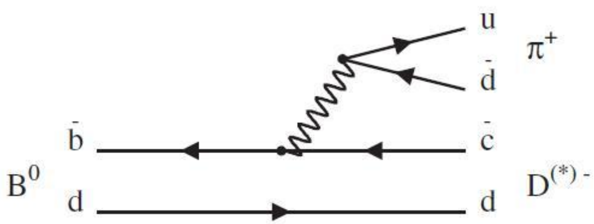


Fig (a) CFD

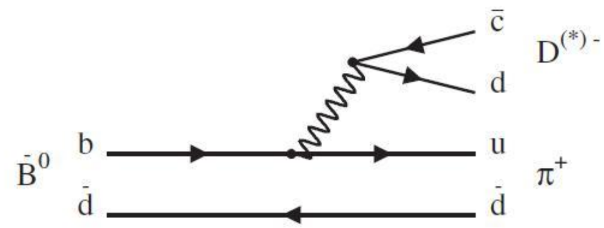


Fig (b) DCSD

Only tree level decays → Theoretically clean

$$\mathcal{P}(B^0 \to D^{(*)+}\pi^-) = 1/(8\tau_{B0})e^{-|\Delta t|/\tau_{B0}}[1 - C\cos(\Delta m\Delta t) - S^+\sin(\Delta m\Delta t)]$$

$$\mathcal{P}(B^0 \to D^{(*)-}\pi^+) = 1/(8\tau_{B0})e^{-|\Delta t|/\tau_{B0}}[1 + C\cos(\Delta m\Delta t) - S^-\sin(\Delta m\Delta t)]$$

$$\mathcal{P}(\overline{B}^0 \to D^{(*)+}\pi^-) = 1/(8\tau_{B0})e^{-|\Delta t|/\tau_{B0}}[1 + C\cos(\Delta m\Delta t) + S^+\sin(\Delta m\Delta t)]$$

$$\mathcal{P}(\overline{B}^0 \to D^{(*)-}\pi^+) = 1/(8\tau_{B0})e^{-|\Delta t|/\tau_{B0}}[1 - C\cos(\Delta m\Delta t) + S^-\sin(\Delta m\Delta t)]$$

$$S^{\pm} = \frac{2(-1)^L R_{D(*)\pi}\sin(2\beta+\gamma\pm\delta)}{(1+R_{D*\pi}{}^2)}$$

$$C = \frac{(1-R_{D(*)\pi}{}^2)}{(1+R_{D(*)\pi}{}^2)}$$

$R_{D(*)\pi}$ is the ratio between amplitudes of the Doubly Cabibbo-Suppressed Decay(DCSD) $B^0 \to D^{*+}\pi^-$ and the Cabibbo-Favored Decay(CFD) $B^0 \to D^{*-}\pi^+$ decay.

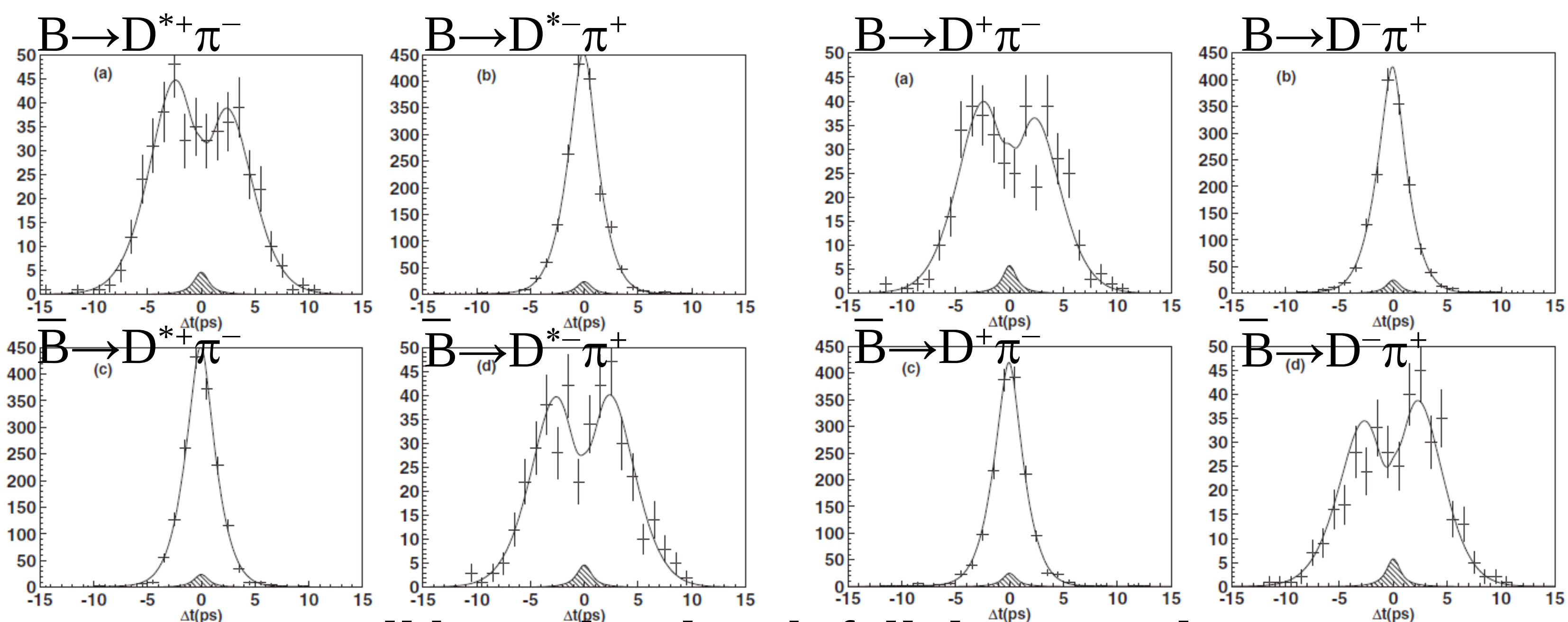
$D^{(*)}\pi$ TCPV w/ Full reconstruction

386M $B\bar{B}$

PRD73(2006)092003

$B \to D^{(*)}\pi$ Full reconstruction analysis
$\downarrow$
$D^{*+} \to D^0\pi$, $D^+\pi^0$
$D^+ \to K\pi\pi$
$D^0 \to K\pi$, $K_s\pi\pi$, $K\pi\pi^0$, $K\pi\pi\pi$

$$S^+(D^*\pi) = 0.050 \pm 0.029 \pm 0.013$$
$$S^-(D^*\pi) = 0.028 \pm 0.028 \pm 0.013$$
$$S^+(D\pi) = 0.031 \pm 0.030 \pm 0.012$$
$$S^-(D\pi) = 0.068 \pm 0.029 \pm 0.012$$



will be updated with full data sample
(x2 stat and higher reconstruction efficiency)

$D^*\pi$ TCPV Partial reconstruction

657M $B\bar{B}$

arXiv:0809.3203

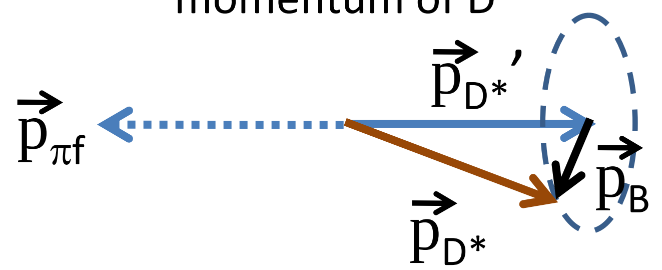
Observed particles

$B \to D^*\pi$ Fast pion π_f

↳ $D^0\pi$ Slow pion π_s

$E_{D*} = E_B - E_{\pi f}$

$p_{D*} = \sqrt{E_{D*}^2 - m_{D*}^2}$

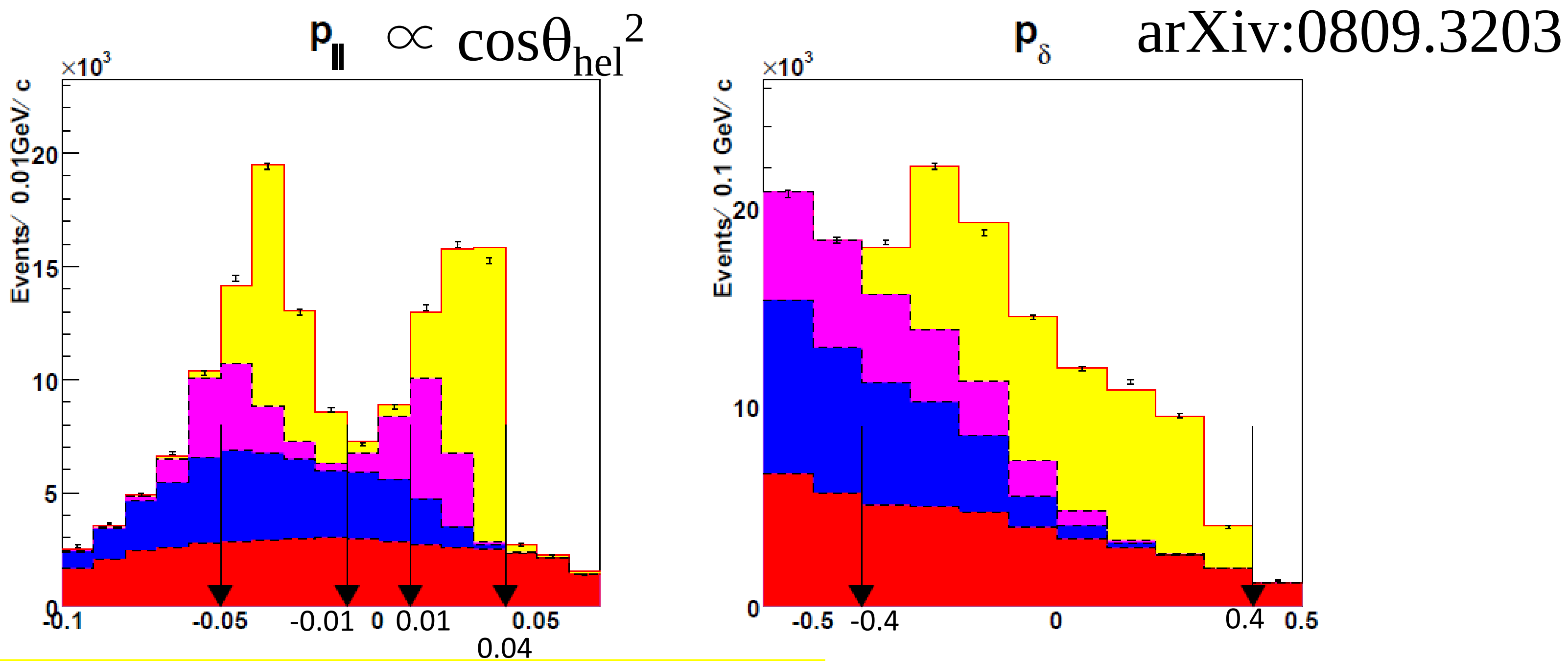


$|\vec{p}_{D*}|$ is known, but the direction is unknown.
We must boost the π_f into the partially reconstructed D* frame.
→This causes the π_s in the actual D* frame, to have a spread in the partially reconstructed D* frame.

Three variables are defined

- parallel and the transverse components of the $p_{\pi s}$ along the opposite direction to π_f . $p_{\parallel}$ and $p_{\perp}$
- Strongly correlated to $p_{\pi f}$. $p_\delta \equiv |p_{\pi f}| - |p_{D*}|$

Event selection and yield fit



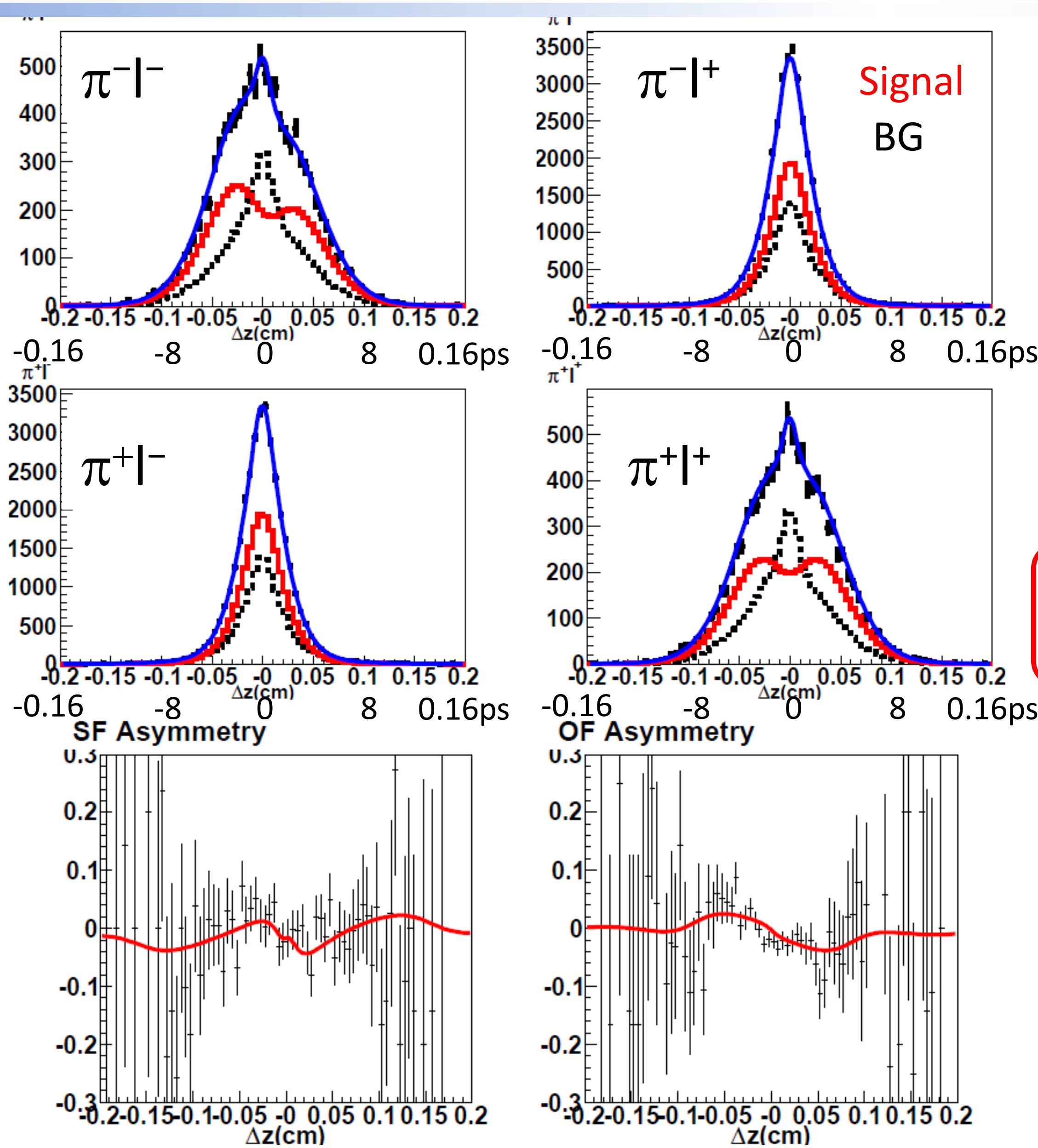
Signal	$D^*\pi$	50192 ± 286
BG	$D^*\rho$	10232 ± 150
	Correlated background	10425 ± 135
	Uncorrelated background	14193 ± 128

Signal purity = $59.0 \pm 0.4\%$

Only lepton tag!

Resulting signal purity and BG fractions used in the CP fit.

$D^{(*)}\pi$ CP fit w/ Partial recon result



arXiv:0809.3203

Here $\pi^\pm$ is the fast pion,
$l^\pm$ is the tag-side lepton

$\pi^\pm l^\pm$ ...Same Flavour(SF)

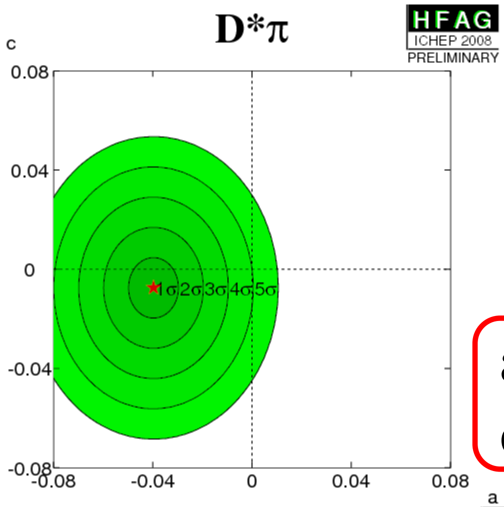
$\pi^\pm l^\mp$ ...Opposite Flavour(OF)

The lepton tag dramatically reduces the qqbar BG

$$S^+ = +0.057 \pm 0.019 \pm 0.012$$
$$S^- = +0.038 \pm 0.020 \pm 0.010$$

Systematic error source	S^+	S^-
Δz offset	0.002	0.003
$\mathcal{R}_k$ parameters	0.002	0.003
$\mathcal{R}_{det}$ parameters	0.002	0.002
$\mathcal{R}_{np}$ parameters	0.008	0.007
Background parameters	0.002	0.003
Physics parameters	0.004	0.004
Yield fit	0.003	0.003
Resolution model	0.006	0.002
Δz floated in background PDF	0.000	0.000
Total systematic error	0.012	0.010

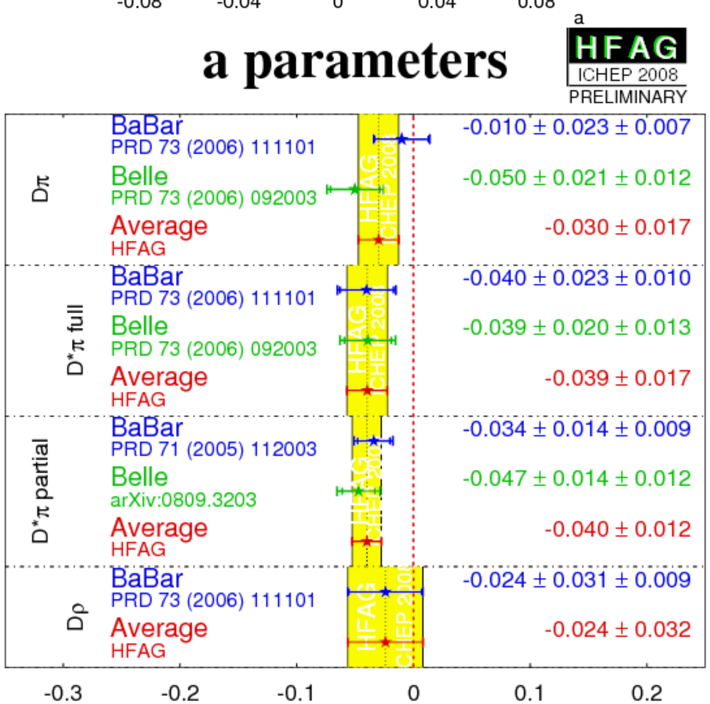
HFAG average

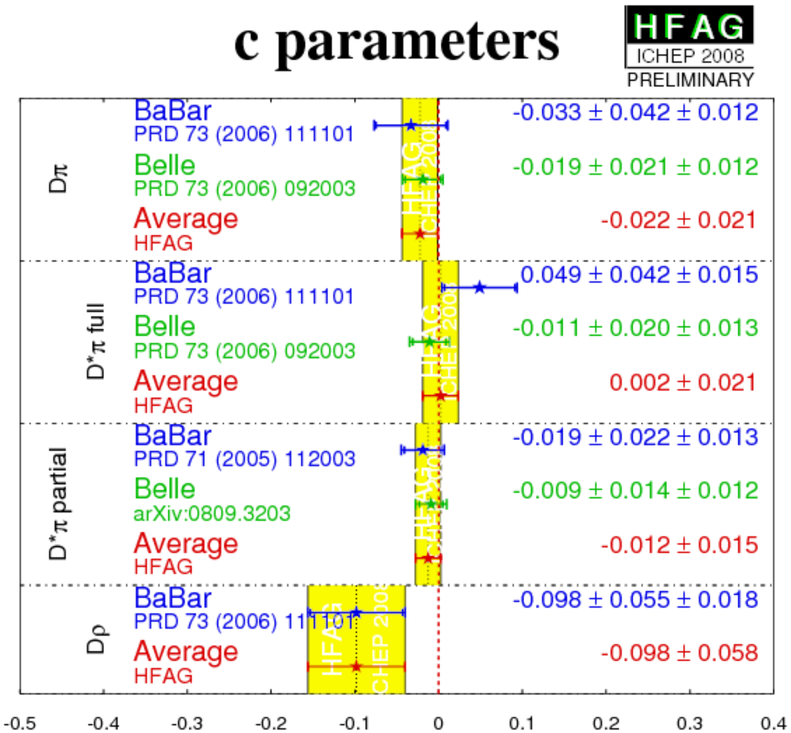


$$S^{+} = +0.057 \pm 0.019 \pm 0.012$$
$$S^{-} = +0.038 \pm 0.020 \pm 0.010$$

HFAG notation

$$a = -(S^{+} + S^{-})/2 = -0.047 \pm 0.014 \pm 0.012$$
$$c = -(S^{+} - S^{-})/2 = -0.009 \pm 0.014 \pm 0.012$$

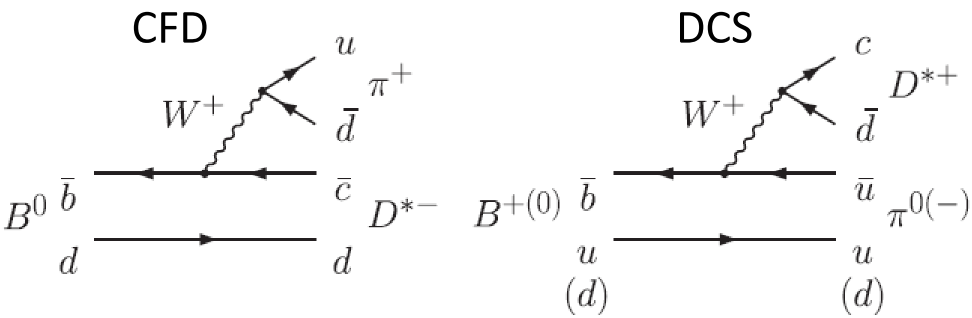




$R_{D^*\pi}$ limit with $D^*\pi^0$

657M $B\bar{B}$

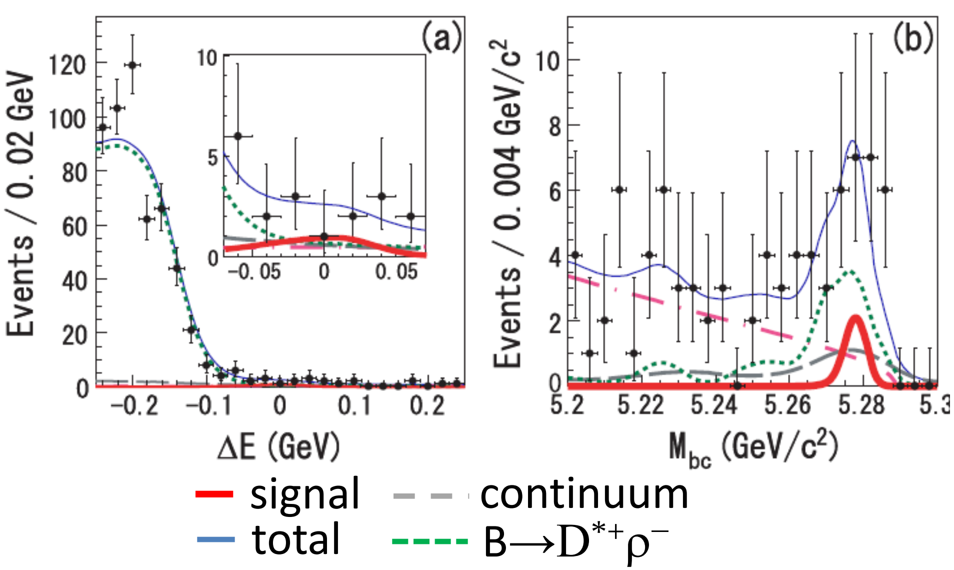
PRL101(2008)041601



$$R_{D^*\pi} = \tan\theta_C \left(\frac{f_{D^*}}{f_{D_s^*}}\right)\sqrt{\frac{\mathcal{B}(B^0 \to D_s^{*+}\pi^-)}{\mathcal{B}(B^0 \to D^{*-}\pi^+)}}$$

→10-15% uncertainty in $R_{D^{*+}\pi^-}$
Max Baak (SLAC-R-858) 2007

$$R_{D^*\pi} = \sqrt{\frac{\tau_{B^0}}{\tau_{B^+}}\frac{2\mathcal{B}(B^+ \to D^{*+}\pi^0)}{\mathcal{B}(B^0 \to D^{*-}\pi^+)}}$$



Using $D^{*+}\pi^0$ and isospin , can determine $R_{D^*\pi}$ with minimal theoretical uncertainty

Where τ_{B+}/τ_{B-} = 1.071±0.009
and $\mathcal{B}(B^0 \to D^{*+}\pi^-) = (2.76 \pm 0.21) \times 10^{-3}$

$\mathcal{B}(B^0 \to D^*\pi^0) = 3.6 \times 10^{-3}$ (90% CL)

$R_{D^*\pi} < 0.051$ (90% C.L)

NEW

$R_{D^*\pi}$ measurement with $D_S^*\pi$

657M $B\bar{B}$ PRD81(2010)031101

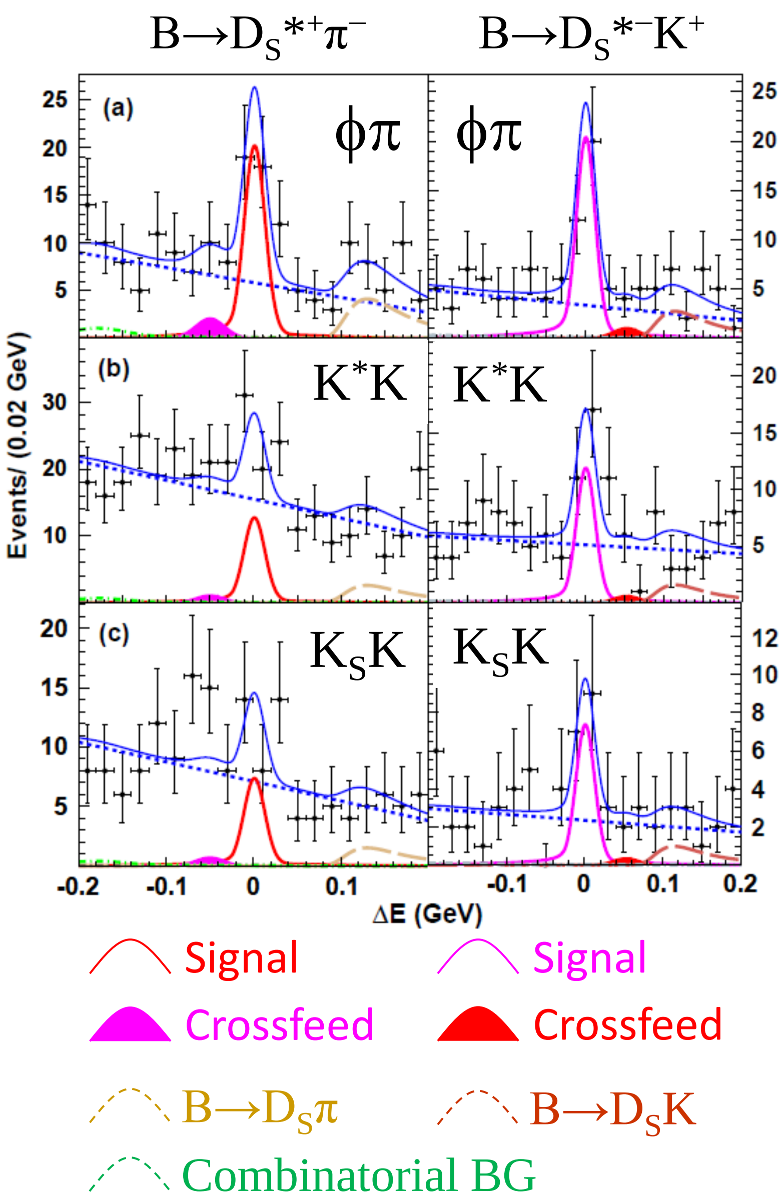
Measuring the DCSD mode, $B^0 \to D^{*+}\pi^-$, is not possible with current data because of the background from $B^0 \to D^{*+}\pi^-$. However, the corresponding background is absent for $\bar{B} \to D_S{}^{*+}\pi^-$. If we assumed SU(3) flavor symmetry, $R_{D^*\pi}$ is given by.

$$R_{D^*\pi} = \tan\theta_C \left(\frac{f_{D^*}}{f_{D_s^*}}\right)\sqrt{\frac{\mathcal{B}(B^0 \to D_s^{*+}\pi^-)}{\mathcal{B}(B^0 \to D^{*-}\pi^+)}}$$

Inputs

- $\tan\theta_C$ =0.2314 ± 0.0021
  …θ_C is Cabbibo-angle
- $\mathcal{B}(B^0 \to D^{*-}\pi^+) = (2.76 \pm 0.13) \times 10^{-3}$ (PDG)
- $f_{D^*}/f_{Ds^{*+}}$ =1.164 ± 0.006 ± 0.020
  …meson form factor estimated the quenched QCD approximation.
- $\mathcal{B}(B^0 \to D_S{}^{*+}\pi^-)$ …this measurement

NEW $R_{D^*\pi}$ measurement with $D_S^*\pi$



PRD81(2010)031101

The D_s^+ is reconstructed in 3 decay modes:

$D_s^+ \to$

$(K^+K^-)_\phi \pi^+$, $(K^-\pi^+)_{K^{*0}(892)}K$, $(\pi^+\pi^-)_{KS}K^+$

D_s^{*+} reconstructed by D_s^+ combining γ:

Simultaneous fit for three D_s^+ decay modes

$\mathcal{B}(B^0 \to D_S^{*+}\pi^-)$
$= (1.75 \pm 0.34 \pm 0.17 \pm 0.11(\mathcal{B})) \times 10^{-5}$ 6.1 σ

$\mathcal{B}(B^0 \to D_S^{*-}K^+)$
$= (2.02 \pm 0.33 \pm 0.18 \pm 0.13(\mathcal{B})) \times 10^{-5}$ 8.0 σ

$R_{D^*\pi} = 1.58 \pm 0.15 \pm 0.10 \pm 0.03\%$
stat . syst. th. error

Most precise determination of $R_{D^*\pi}$ so far!

$R_{D\pi}$ measurement with $D_S\pi$

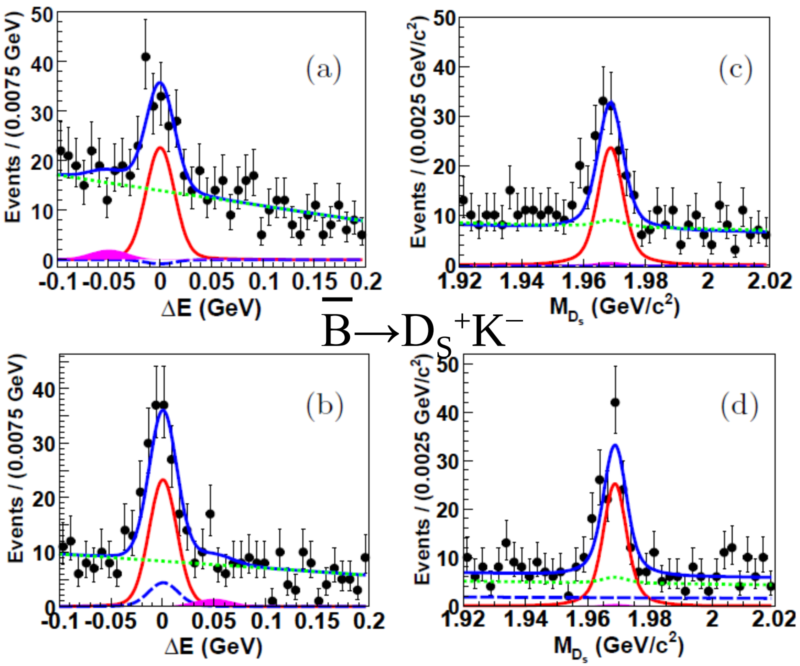
NEW

657M $B\bar{B}$

arXiv:1007.4619
Accepted by PRD

$B \to D_S^+\pi^-$

$\bar{B} \to D_S^+K^-$



Total
Signal
Crossfeed
Charmless B BG
Combinatorial BG

D_s^+ reconstructed by 3 decay modes:
$(K^+K^-)_\phi\pi^+$, $(K^-\pi^+)_{K^{*0}(892)}K$, $(\pi^+\pi^-)_{KS}K^+$

$$R_{D\pi} = \tan\theta_C \frac{f_D}{f_{D_s}} \sqrt{\frac{\mathcal{B}(B^0 \to D_s^+\pi^-)}{\mathcal{B}(B^0 \to D^-\pi^+)}}$$

$\mathcal{B}(B^0 \to D_S^+\pi^-)$
$= (1.99 \pm 0.26 \pm 0.18) \times 10^{-5}$ 8.0 σ

$\mathcal{B}(\bar{B}^0 \to D_S^+K^-)$
$= (1.91 \pm 0.24 \pm 0.17) \times 10^{-5}$ 9.2 σ

$R_{D\pi} = 1.71 \pm 0.11 \pm 0.09 \pm 0.02\%$
stat . syst. th. error

Most precise determination of $R_{D\pi}$ so far!

Conclusions

- $D^*\pi$ partial reconstruction updated arXiv:0809.3203

$$a = -(S^+ + S^-)/2 = -0.047 \pm 0.014 \pm 0.012$$
$$c = -(S^+ - S^-)/2 = -0.009 \pm 0.014 \pm 0.012$$

→Update of the full reconstructed method with full Belle data sample in progress.

PRL101(2008)041601

- $R_{D*\pi}$ measurement with $D^*\pi^0$
- $R_{D(*)\pi}$ measurement with $D_S^{(*)}\pi$

New results

$$R_{D*\pi} = 1.58 \pm 0.15 \pm 0.10 \pm 0.03\%$$
stat . syst. th. error

PRD81(2010)031101

$$R_{D\pi} = 1.71 \pm 0.11 \pm 0.09 \pm 0.02\%$$
stat . syst. th. error

arXiv:1007.34619

Most precise determination of $R_{D(*)\pi}$

Backup slides for partial recon.

CP side selection

dr < 0.1cm (|dz| <2.0cm)
Reject lepton and kaon based PID info from fast pion candidate.
1.93GeV/c < $p_{\pi f}$ < 2.50GeV/c
0.05GeV/c < $p_{\pi s}^{*}$ < 0.30GeV/c
0.00GeV/c < $p_{\perp}$ < 0.06GeV/c
-0.60GeV/c < p_{δ} < 0.5GeV/c
-0.10GeV/c < $p_{\parallel}$ < 0.07GeV/c

Signal region
-0.40GeV/c < p_{δ} < 0.40GeV/c
-0.05GeV/c < $p_{\parallel}$ < -0.01GeV/c
0.01GeV/c < $p_{\parallel}$ < 0.04GeV/c

tag side selection

1.1GeV/c < p_{l} < 2.3GeV/c
-0.75<$\cos\delta_{\pi fl}$ in the c.m.s
R_2 < 0.6

$$|\sin(2\phi_1 + \phi_3)| > 0.44(0.13) \quad \text{at } 68\%(95\%)\text{CL}$$

from the results for the $D^*\pi$ mode and

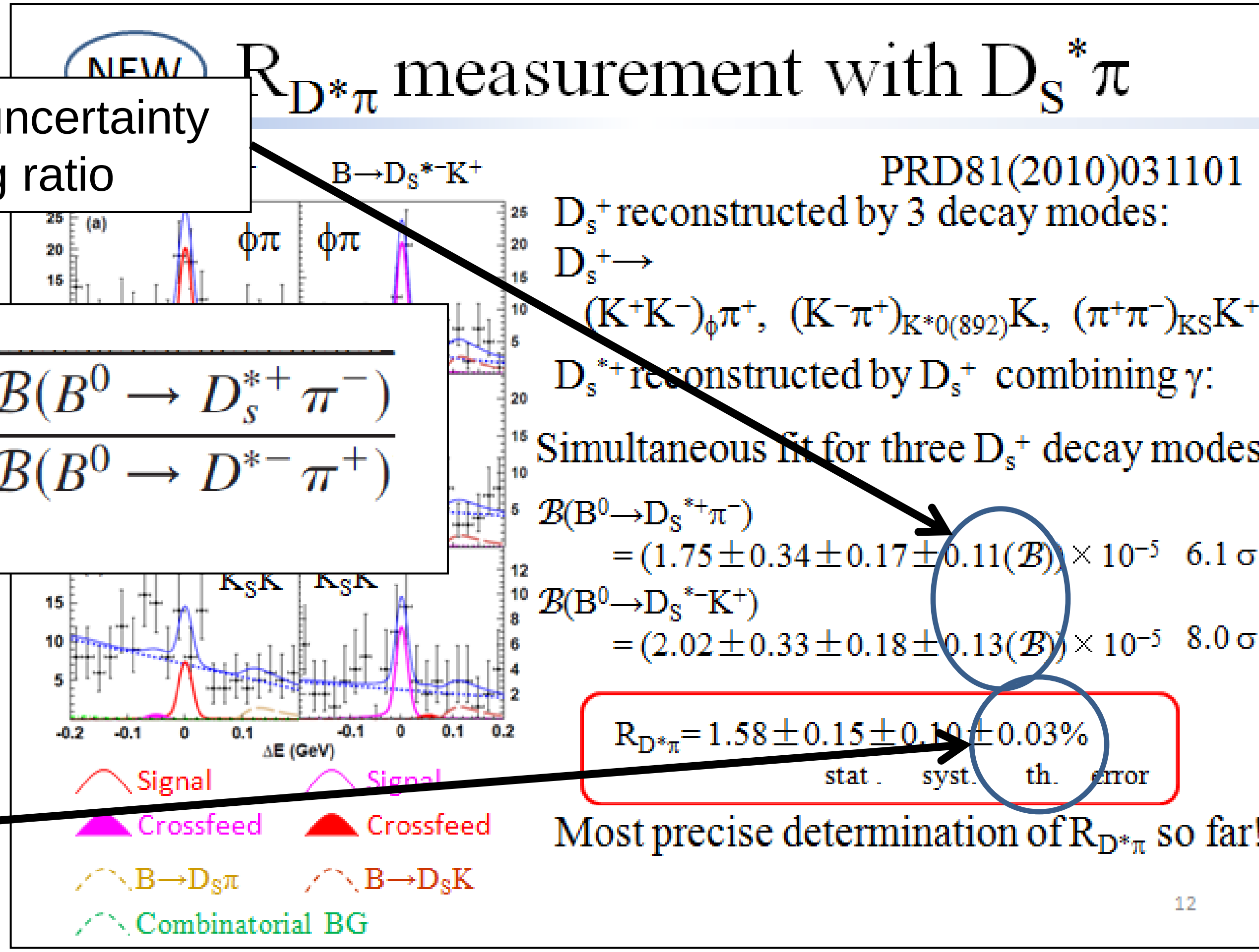
$$|\sin(2\phi_1 + \phi_3)| > 0.52(0.07) \quad \text{at } 68\%(95\%)\text{CL}$$

Backup slides for $D_s^*\pi$

Backup slide of $R_{D^*\pi}$ with $D_s^*\pi$

The third errors are from uncertainty in the D_s^+ decay branching ratio

$$R_{D^*\pi} = \tan\theta_C \left(\frac{f_{D^*}}{f_{D_s^*}}\right)\sqrt{\frac{\mathcal{B}(B^0 \to D_s^{*+}\pi^-)}{\mathcal{B}(B^0 \to D^{*-}\pi^+)}}$$



We have assumed

$f_{Ds} / f_D = f_{D^*s} / f_{D^*}$

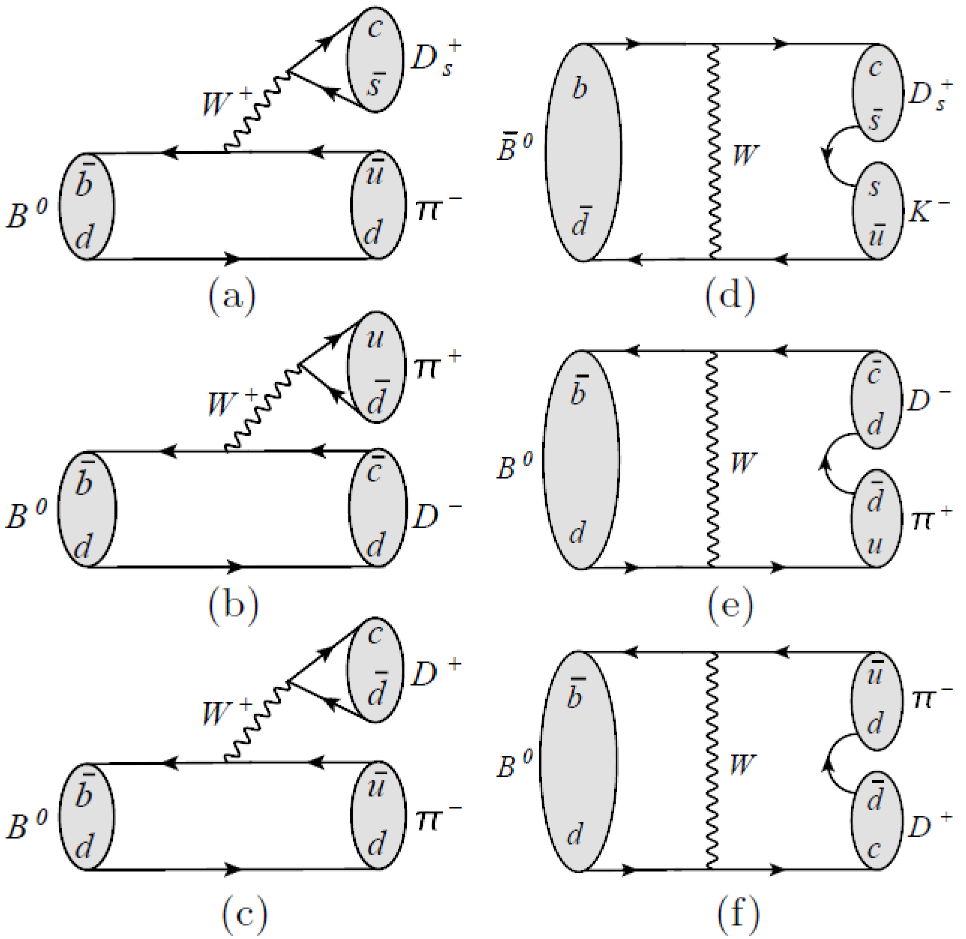
The quenched QCD approximation(heavy quark effective theory) predicts the uncertainty of the assumption 1%

$Br(B \to D_S^* \pi)$ significance and systematic err.

B^0 mode	D_s^+ mode	ϵ (%)	N_{sig}	$\mathcal{B}(10^{-5})$	$\mathcal{S}$ (σ)
$B^0 \to D_s^{*+}\pi^-$	$\phi(K^+K^-)\pi^+$	15.2	32 ± 8	$1.58 \pm 0.40 \pm 0.24$	3.2
	$\bar{K}^*(892)^0(K^-\pi^+)K^+$	7.9	29 ± 10	$2.30 \pm 0.76 \pm 0.35$	2.6
	$K_S^0 K^+$	8.0	13 ± 7	$1.78 \pm 0.92 \pm 0.11$	2.2
	Simultaneous	-	-	$1.75 \pm 0.33 \pm 0.11$	6.6
$B^0 \to D_s^{*-}K^+$	$\phi(K^+K^-)\pi^+$	13.4	33 ± 8	$1.81 \pm 0.41 \pm 0.27$	3.2
	$\bar{K}^*(892)^0(K^-\pi^+)K^+$	6.4	23 ± 7	$2.22 \pm 0.66 \pm 0.34$	2.8
	$K_S^0 K^+$	6.9	14 ± 5	$2.14 \pm 0.80 \pm 0.13$	3.1
	Simultaneous	-	-	$2.02 \pm 0.33 \pm 0.13$	8.6

Source	Contribution(%)	
	$D_s^{*+}\pi^-$	$D_s^{*+}K^-$
$\mathbf{D}_s^+$ branching fraction uncertainties		
signal	5.9	6.2
peaking background	1.5	1.9
Total ($\mathcal{B}$)	**6.1**	**6.5**
Tracking efficiency	4.0	4.0
Photon detection efficiency	7.0	7.0
Particle identification efficiency	2.4	2.1
K_S^0 efficiency	1.1	1.1
$\mathcal{LR}$	0.6	0.5
N_{BB}	1.4	1.4
MC statistics	1.4	1.6
PDF shape	3.4	1.5
Fit bias	0.9	0.3
Total (other)	**9.4**	**8.8**

W-exchange contribution



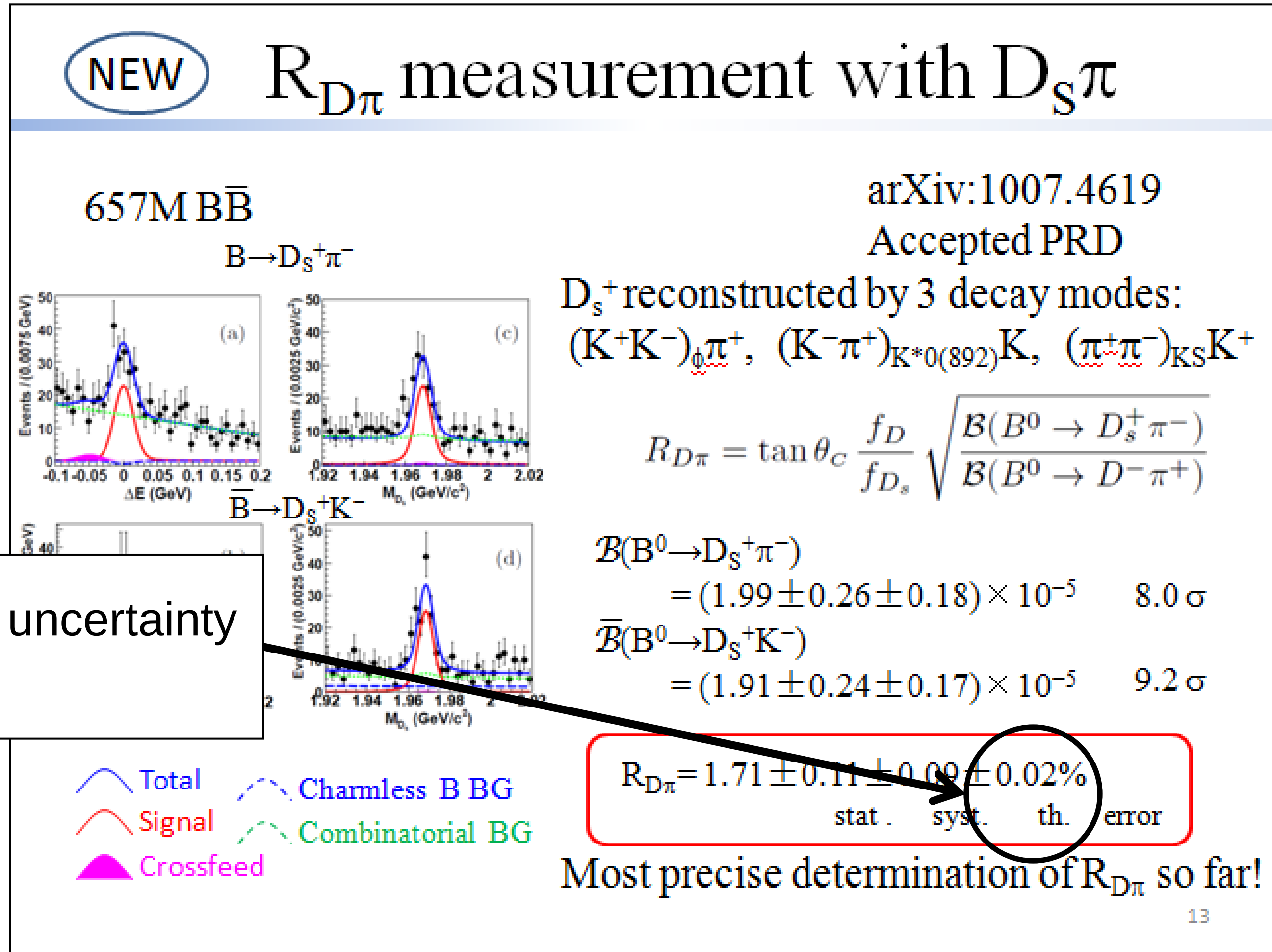
Potential contributions arising from rescattering effects could enhance its branching fraction. Recent studies, however, find the rescattering contribution to be negligible.

$\mathcal{B}(B^0 \to D_S^{*-}K^+)$
$= (2.02 \pm 0.33 \pm 0.18 \pm 0.13(\mathcal{B})) \times 10^{-5}$
$\mathcal{B}(B^0 \to \bar{D}_S^{+}K^-)$
$= (1.91 \pm 0.24 \pm 0.17) \times 10^{-5}$

The measured values can be understood in terms of a pure W-exchange contribution, which is in agreement with both measurement.

Backup slides for $D_s\pi$

Backup slide of $R_{D\pi}$ with $D_s\pi$



Accounts for the theory uncertainty in the f_D/f_{Ds} estimation.

Uncertainty due to other possible SU(3) breaking effect are not included in the theory error

Br($B \to D_s \pi$) significance and systematic err.

B mode	D_s^+ mode	ϵ (%)	$N_{\rm sig}$	$N_{\rm chmls}$	$\mathcal{B}$ (10^{-5})
$B^0 \to D_s^+ \pi^-$	$\phi(K^+K^-)\pi^+$	21.64	64 ± 10	0 ± 8	2.08 ± 0.34
	$\overline{K}^{*0}(K^-\pi^+)K^+$	11.18	33 ± 9	-7 ± 17	1.71 ± 0.49
	$K_S^0 K^+$	15.70	24 ± 9	-4 ± 13	2.21 ± 0.83
	Simultaneous fit result				$1.99 \pm 0.26 \pm 0.18$
$\overline{B}^0 \to D_s^+ K^-$	$\phi(K^+K^-)\pi^+$	21.96	61 ± 10	14 ± 10	1.97 ± 0.31
	$\overline{K}^{*0}(K^-\pi^+)K^+$	11.11	39 ± 9	27 ± 14	2.04 ± 0.47
	$K_S^0 K^+$	14.89	19 ± 11	31 ± 12	1.20 ± 0.68
	Simultaneous fit result				$1.91 \pm 0.24 \pm 0.17$

TABLE II: Summary of the systematic uncertainty.

Source	Systematic contribution (%) to	
	$\mathcal{B}(B^0 \to D_s^+ \pi^-)$	$\mathcal{B}(\overline{B}^0 \to D_s^+ K^-)$
D_s^+ branching fraction	$+6.59, -6.51$	$+6.31, -6.14$
PDF shape	$+1.44, -1.79$	$+1.28, -1.33$
MC statistics	$+0.39, -0.48$	$+0.46, -0.45$
K_S^0 reconstruction	$+0.45, -0.40$	± 0.63
PID efficiency	± 2.78	± 3.06
Tracking efficiency	± 4.00	± 4.00
Error on $N_{B\overline{B}}$	± 1.40	± 1.40
Requirements on $\mathcal{R}$	± 1.60	± 1.60
Fit bias	± 3.42	± 2.09
Total	$+9.26, -9.27$	$+8.74, -8.62$

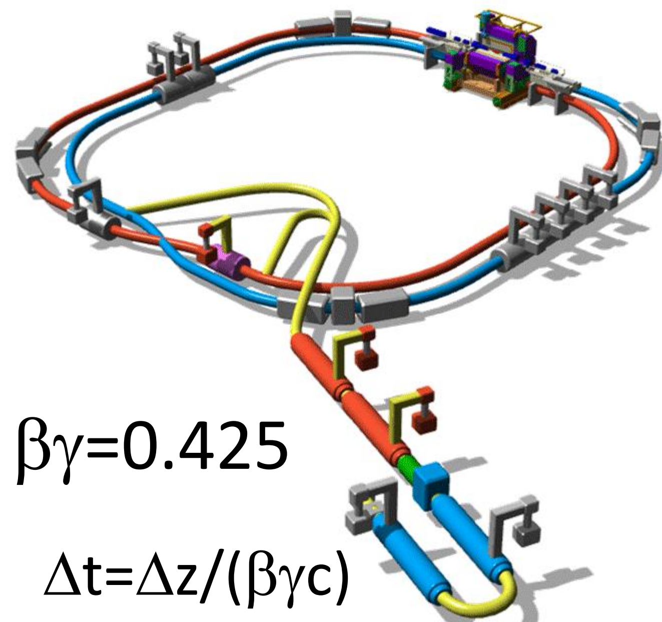
KEKB at KEK

8 GeV e^- and 3.5 GeV e^+
±11mrad crossing

on resonance of Y(4S)~10.58GeV

Y(4S) : $q\bar{q}$(continuum)= 1:3

Br(Y(4S) → $B\bar{B}$)>96%



$\beta\gamma$=0.425

$\Delta t = \Delta z/(\beta\gamma c)$

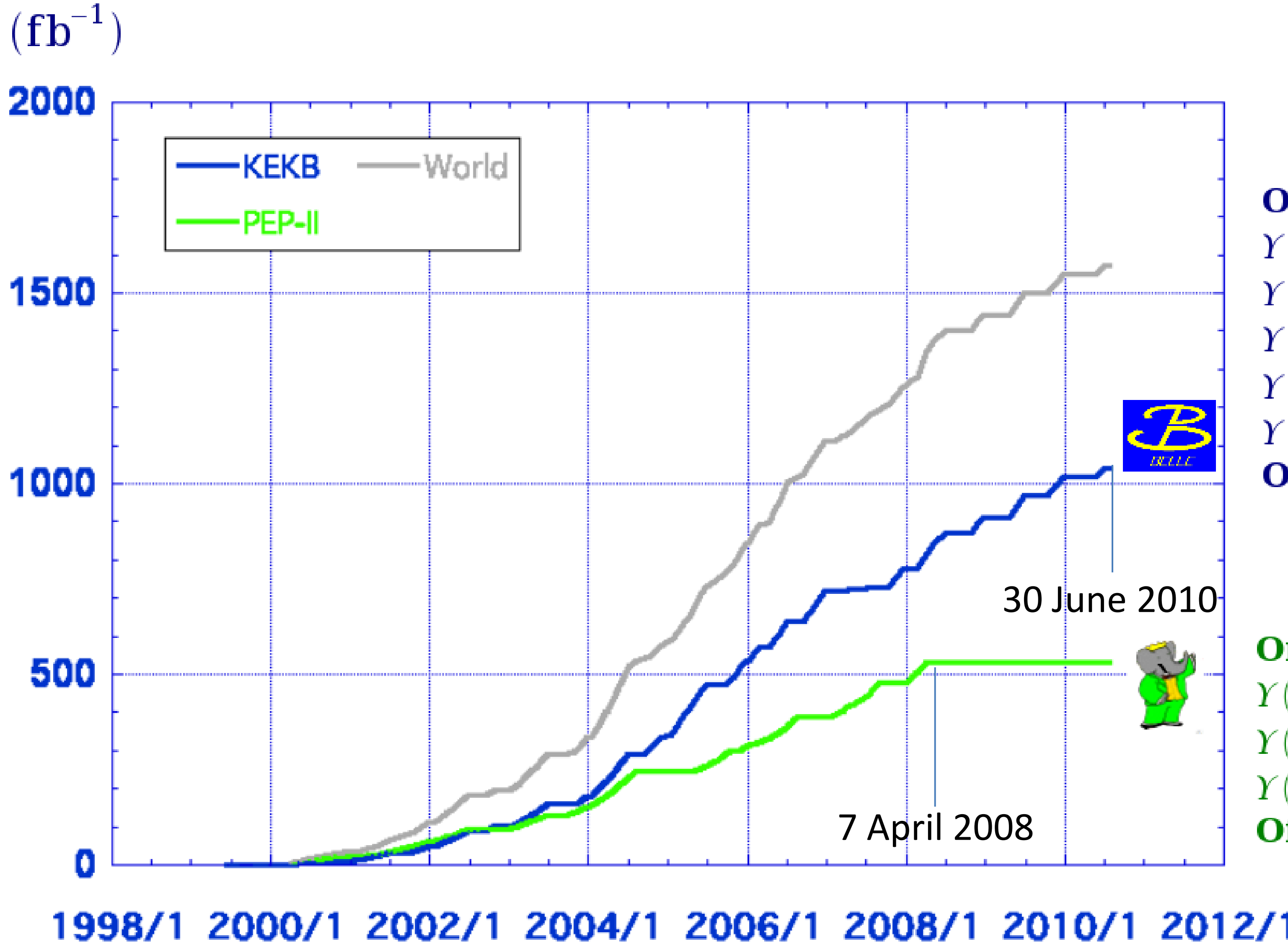
$L_{peak} = 2.1 \times 10^{34}\ \mathrm{sec^{-1}cm^{-2}}$

>Twice of the design Luminosity !

Producing enormous $B\bar{B}$ pairs copiously

→ B-factory

Luminosity at B factories



> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 24 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

$\sim$ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1}

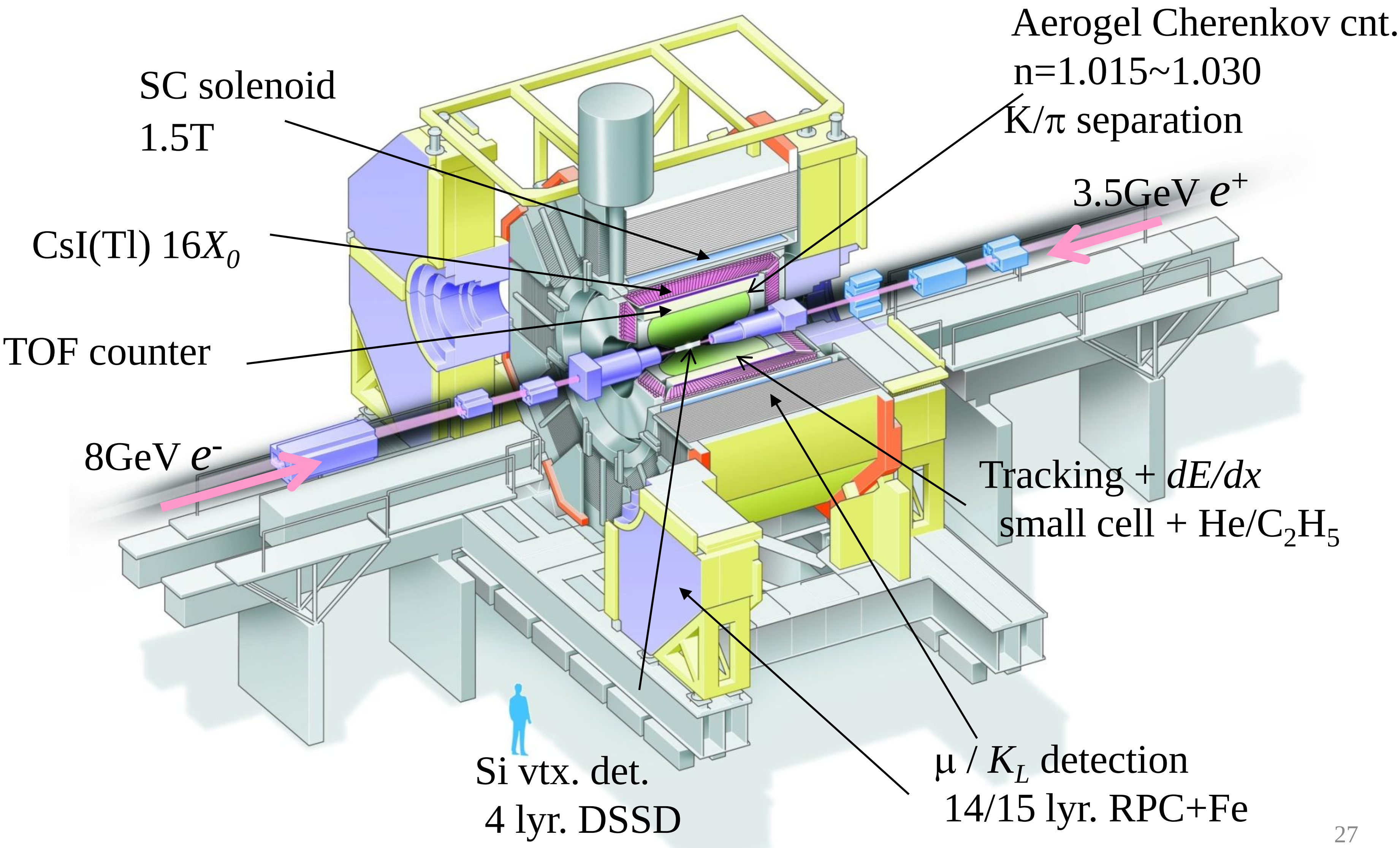
$\Upsilon(3S)$: 30 fb^{-1}

$\Upsilon(2S)$: 14 fb^{-1}

Off resonance:

$\sim$ 54 fb^{-1}

Belle Detector



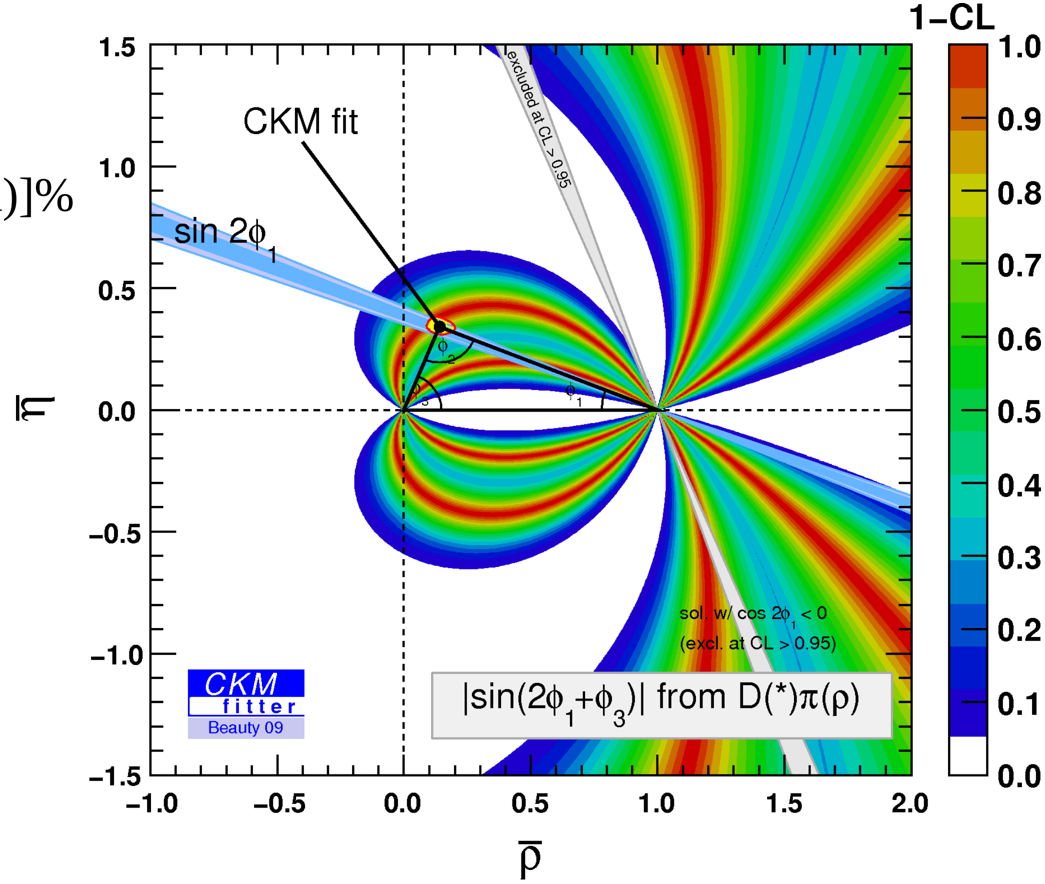
$D^{(*)}\pi$ TCPV for $\sin(2\phi_1+\phi_3)$

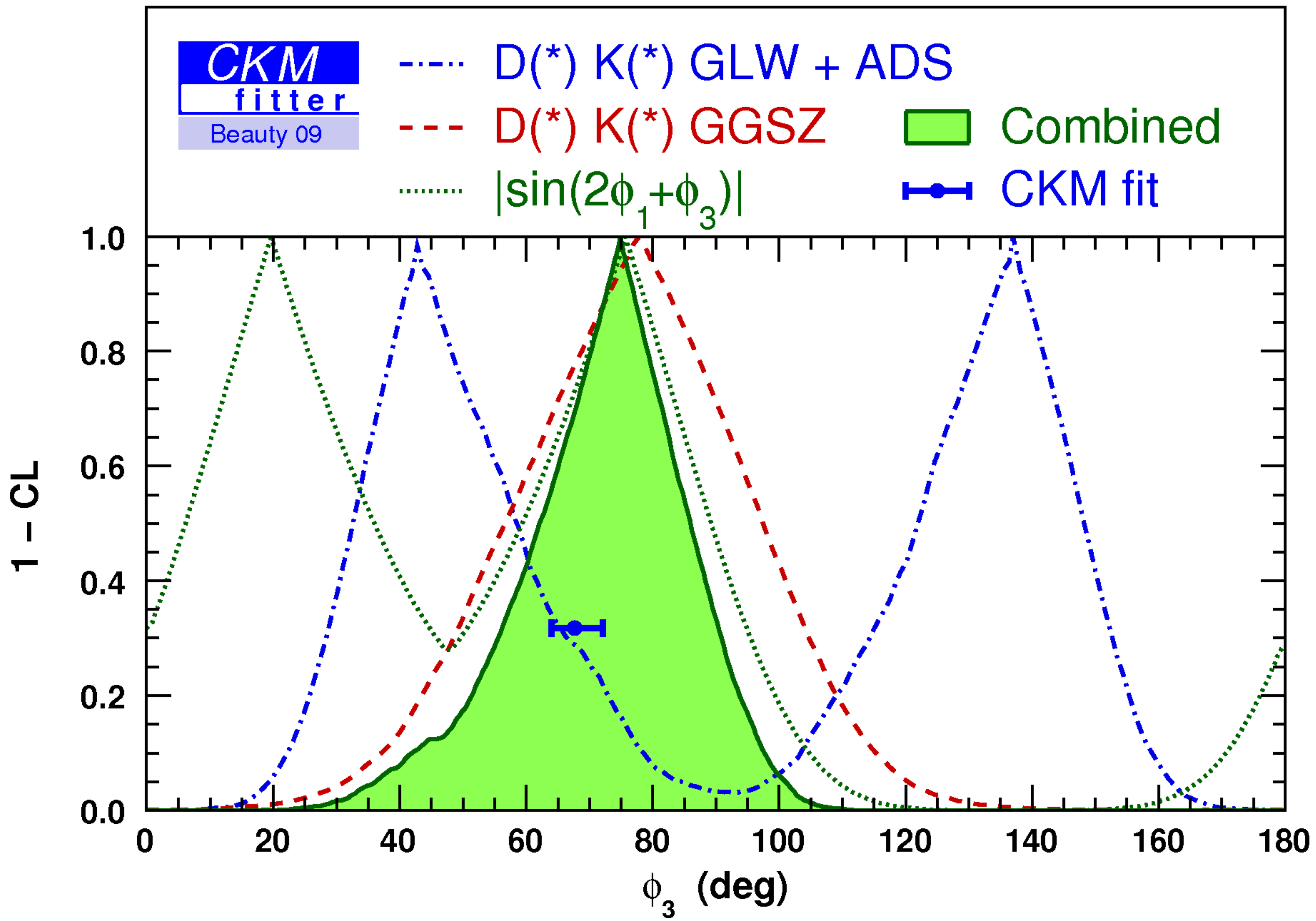
input

r = $[1.81\ ^{+0.16}_{-0.15}$ (stat)$\pm$0.09(syst) $\pm$0.10(th)]%

PRD78,032005

Assuming SU(3) flavor symmetry*




CKM fitter
Beauty 09
D(*) K(*) GLW + ADS
D(*) K(*) GGSZ
|sin(2φ1+φ3)|
Combined
CKM fit
1 – CL
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
120
140
160
180
φ3 (deg)

Comparison with LHCb